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Environmental Implementation Guide
for Radiological Survey Procedures

Office of Environmental Policy and Assistance
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4. SURVEY PROCEDURES

4.1 SITE PREPARATION

4.1.1 Property Boundaries/Civil Survey

Property boundaries may be determined from property survey maps furnished by the owners or from plat maps obtained from city or county tax maps. Large-area properties or properties that are overgrown or have survey markers missing may require the services of a professional land surveyor.

If the radiological survey is to be performed inside buildings only and grounds are excluded, a tax map with the buildings accurately located will usually suffice for site/building location designation. If grounds are included or if it appears that characterization or remediation will be necessary, a plat map prepared by a licensed land surveyor may be required.

4.1.2 Clearing to Provide Access

4.1.2.1 Indoor

Indoor areas must be sufficiently cleared to permit completion of the survey. Clearing includes providing access to potentially contaminated interior surfaces (e.g., drains, ducting, tanks, pits, ceiling areas, and equipment) by removing covers, disassembly, or other means of producing adequate openings.

Building design and condition will have a marked influence on the survey efforts. The time to conduct a survey of building interior surfaces is generally proportional to the total surface area. The degree of survey coverage necessary to make an adequate assessment may also be decreased as the potential for residual activity decreases.

Building construction features such as ceiling height and incorporation of ducts, pipes, and certain other services into the construction will determine the ease of accessibility of various areas. Scaffolding, cranes, man lifts, or ladders may be necessary to reach some surfaces. Accessing some locations may actually require dismantling portions of the building. If the building is constructed of porous materials such as wood or concrete and the surface was not sealed, contamination may have found its way into the walls, floors, and other surfaces. It may be necessary to obtain cores for laboratory analysis. Another common difficulty is the presence of contamination beneath tile or other floor coverings. This occurs because the covering placed over contaminated surfaces or the joints in tile was not sealed to prevent penetration. It has been the practice in some facilities to "fix" contamination (particularly alpha emitters) by painting over the surface of the contaminated area. General guidance on dealing with covered or absorbed contamination is given in Sect. 4.3. All this must be addressed in surveys.

The presence of furnishings and equipment will restrict access to building surfaces and is an additional item that must be addressed. In cases where equipment indirectly involved in the original processing activities remains, relatively inaccessible surfaces may require dismantling in order to evaluate their radiological status. It may also become necessary to remove or relocate certain furnishings such as lab benches and hoods to obtain access to potentially contaminated floors and walls. The amount of effort and resources dedicated to such removal or relocation activities should be commensurate with the potential for contamination. Where the potential is low, a few spot-checks may be sufficient to provide confidence that hidden areas are free of contamination. In other cases, complete removal may be warranted.

Piping, drains, sewers, sumps, tanks, and other components of liquid handling systems present special difficulties because of the inaccessibility of interior surfaces. Process information, operating history, and preliminary monitoring at available access points will assist in evaluating the extent of sampling and measurements that will be required.

Expansion joints, stress cracks, and penetrations into floors and walls for piping, conduits, and anchor bolts, etc., are potential sites for accumulation of contamination and pathways for migration into subfloor soil and hollow wall spaces. Wall/floor interfaces are also likely locations for residual contamination. Coring, drilling, or other such methods may be necessary to gain access to survey.

Exterior building surfaces will typically have a low potential for residual contamination; however, there are several locations that should be surveyed. If there were roof exhausts or the facility is proximal to air effluent discharge points, the possibility of roof contamination must be considered. Because roofs are periodically resurfaced, contaminants may have been covered by roofing material, and sampling of this material may be necessary. Wall penetrations for process equipment, piping, and exhaust ventilation are potential locations for exterior contamination. Roof drainage points such as driplines along overhangs, downspouts, and gutters are also important survey locations. Window ledges and outside exits (doors, doorways, landings, stairways, etc.) are also building exterior surfaces that must be addressed.

4.1.2.2 Outdoor

If ground cover must be removed or if there are other obstacles that limit access by either survey personnel or by necessary equipment (e.g., electromagnetic scanners and subsurface sampling rigs) the time and expense of making land areas accessible must be considered. In addition, precautionary procedures must be developed to prevent spreading surface contamination during ground cover removal and/or the use of heavy equipment.

Removal or relocation of equipment and materials that may entail special precautions to prevent damage or maintain inventory accountability should be performed by the property owner whenever possible. Clearing open land of brush and weeds will

usually be performed by a professional land-clearing organization under subcontract arrangements. However, survey personnel may perform limited minor land clearing activities as required.

An important consideration prior to clearing is the possibility of bio-uptake and consequent radiological contamination of the material to be cleared. Special precautions to avoid exposure of personnel involved in clearing activities may be required. Initial radiological screening surveys should be performed to ensure that cleared material or equipment is not contaminated.

The extent of site clearing required in specific areas will depend on the potential for radioactive contamination existing in those areas. If the radiological history and/or results of previous surveys do not indicate potential contamination of an area, it may be sufficient to perform only minimum clearing to establish a reference grid system. However, when contamination is known to or has a high potential to exist, then the area must be completely cleared to provide access to all surfaces. One should also be aware that if minimal clearing has been performed and contamination is found, then additional clearing will likely be required in order to gain access to the remaining areas.

Open land areas may be cleared by heavy machinery (e.g., bulldozers, bushhogs, and hydroaxes); however, care must be exercised to prevent relocation of surface contamination or damage to site features such as drainage ditches, utilities, fences, and buildings. Minor land clearing may be performed using manually operated equipment such as brushhooks, power saws, knives, and weedwhackers. Brush and weeds should be cut to the minimum practical height, not to exceed 15 cm (6 in.). Care should be exercised to prevent unnecessary damage to or removal of mature trees or shrubs.

Surveys should also consider potential ecological damage that might result from an extensive survey. If a survey is likely to result in significant or permanent damage to the environment, appropriate environmental analyses should be conducted prior to initiating the survey. Such conditions may require staged survey efforts to ensure that benefits exceed possible risks or damage resulting from survey efforts.

4.1.3 Reference Grid System

The radiological measurements and samples should be collected relative to a grid system that has been prepared for the area. It should be noted that the grids described are intended for reference purposes and do not necessarily dictate the spacing of survey measurements or sampling. Closer-spaced or other variously described survey locations may be required to demonstrate that average and hot-spot guidelines are met to the required level of confidence (see Sect. 4.2.4). Grid systems are established at the site to:

- facilitate selection of systematic measuring/sampling locations,
- provide a mechanism for referencing a measurement/sample back to a specific location so that the same survey point can be relocated, and
- provide a convenient means for documenting average activity levels.

The system is established in reference to a fixed site location or benchmark. Typically, the grid system consists of mutually perpendicular lines spaced at equal

intervals dividing the survey location into squares or blocks of equal area; however, other types of patterns (triangular, rectangular, hexagonal) have been used for survey reference purposes. The intersections of these grid lines are referred to as grid points. The smallest squares enclosed by the grid lines are called grid blocks. A contiguous collection of grid blocks comprises a grid area (or survey unit).

Following establishment of the grid system, a drawing is prepared by the survey team or the land surveyor. This drawing indicates the grid, site boundaries, and other pertinent site features, and provides a legend showing the scale and a reference compass direction.

4.1.3.1 Indoor

A common grid spacing for building interiors is 1 m (3.25 ft); however, spacing will vary depending upon the needs of the survey (see Sect. 4.2.4). Grid size may be increased for areas having a low potential for contamination, or decreased in areas of heavier contamination. Adjustment of grid size may be particularly applicable to areas where there is no documented or verifiable evidence that any radioactive materials were ever stored or used there. Thus, grids of greater than 1 m (3.25 ft) may be used where there is knowledge that no radioactive material was ever used. Gridding may be limited to the floor and lower walls [up to 2-m (6.4-ft) height], unless there is also a potential for upper wall and ceiling area contamination. Horizontal grid patterns are typically identified numerically on one axis and alphabetically on the other axis. The floor grid pattern is usually extended up vertical surfaces (walls). Overhead measurement/sampling locations (e.g., ceiling and overhead beams) are referenced to corresponding floor grids. An example of a typical building grid is shown in Fig. 4.1. For some radionuclides, scanning surveys have adequate sensitivity to detect the approved authorized limit. Under these circumstances, grid sizes may be irrelevant.
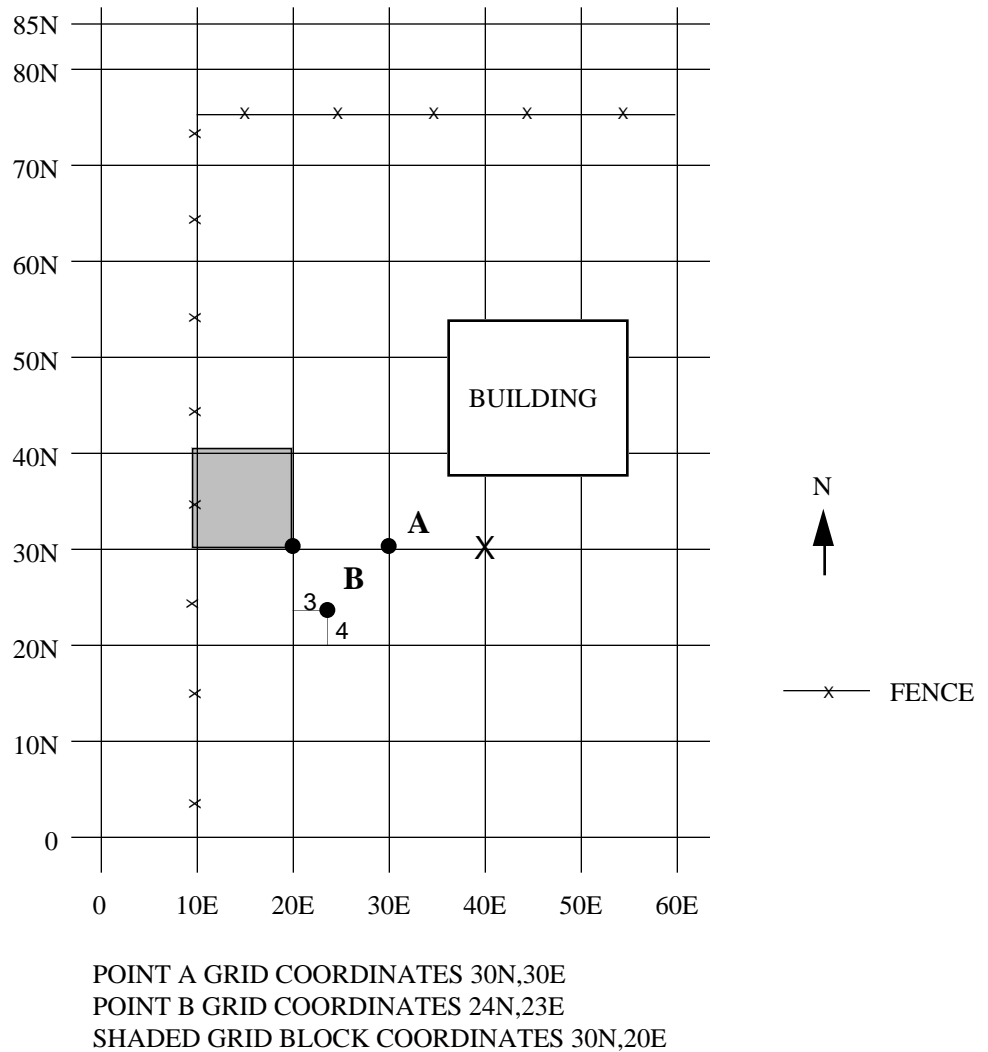
4.1.3.2 Outdoor

Scoping surveys of small area properties (e.g., residences or small commercial properties) can be performed without the benefit of gridding. Large, open land areas and all properties receiving a characterization survey should be gridded. Typical open land grids are illustrated in Figs. 4.2 and 4.3.
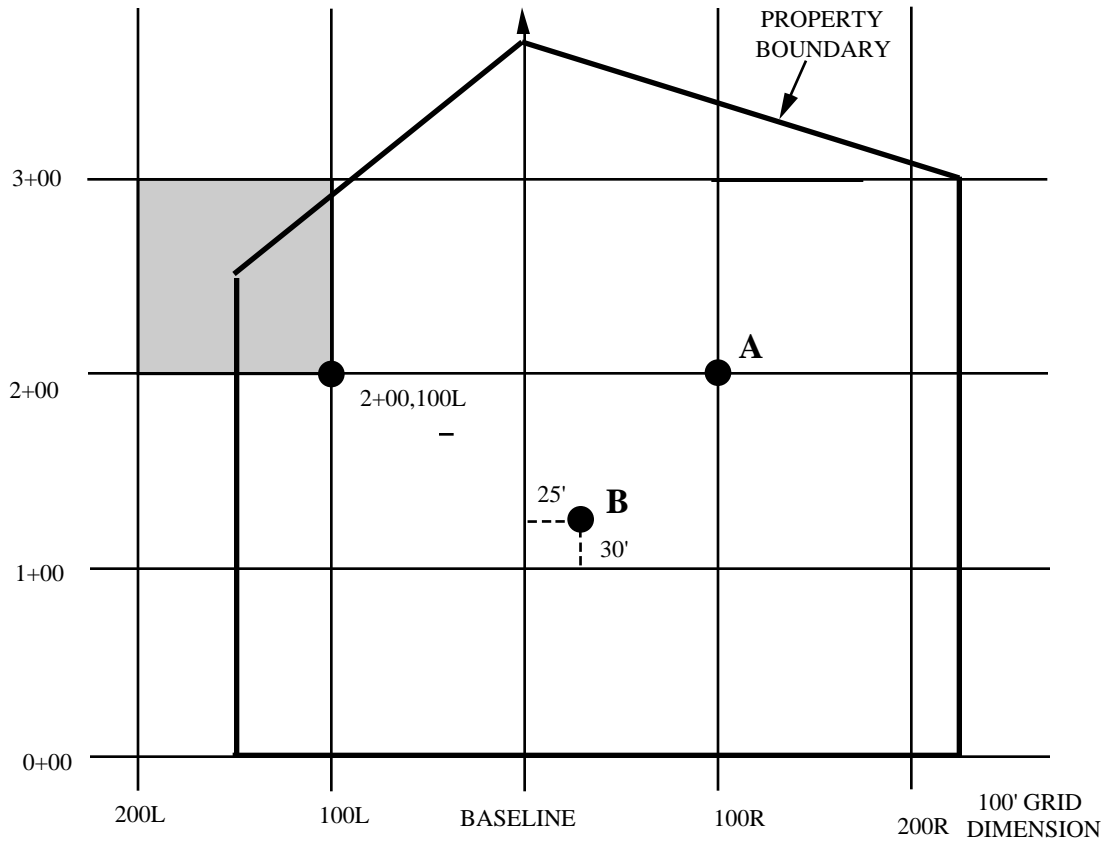
The grid area considered appropriate for outdoor surveys under the current guideline structure is 100 m^2 (1076 ft^2), the area over which data must be averaged in order to compare findings with guidelines. The grid size may be increased or decreased depending on the potential for contamination and the type of survey being performed (see Sect. 4.2.4). This may include areas having a low probability for contamination for a variety of possible reasons, e.g., areas subject to contamination by windblown residues originating from nearby contaminated sites or properties. On the other hand, when performing a confirmatory/verification survey to assess the adequacy of remedial action, a 2.5-m (9.6 ft) grid system might be appropriate for decontaminated areas of 100 m^2 (1076 ft^2) or larger. For areas less than 25 m^2 (269 ft^2), a 1-m (3.25-ft) grid system may be used.
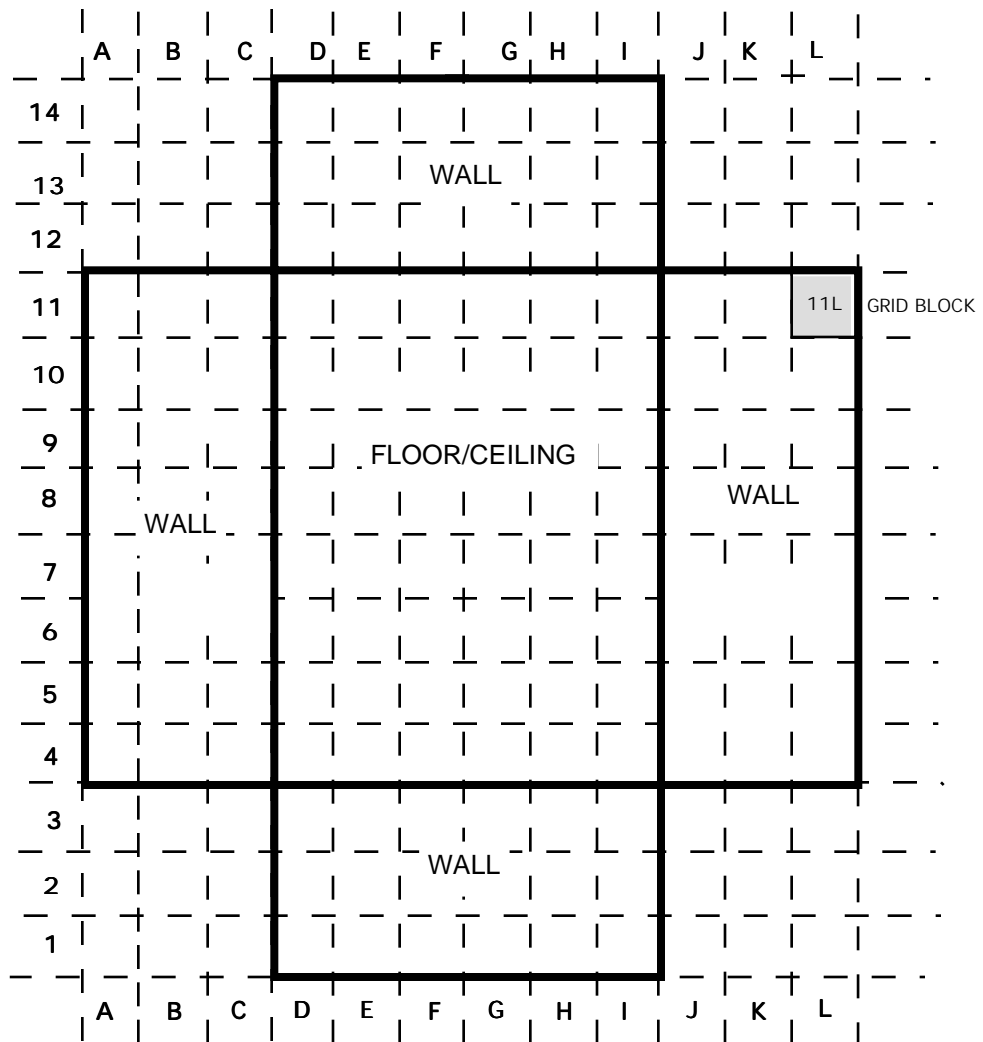
Fig. 4.1. Typical grid layout with alphanumeric grid block.
Walls and floor are diagrammed as though they lay   along the same
horizontal plane.

POINT A GRID COORDINATES 30N,30E
POINT B GRID COORDINATES 24N,23E
SHADED GRID BLOCK COORDINATES 30N,20E

Fig. 4.2. Example of grid system for survey of site grounds using compass directions.

POINT A GRID COORDINATES 2+00,100R
POINT B GRID COORDINATES 1+30,25R
SHADED GRID BLOCK COORDINATES 2+00,100L

Fig. 4.3. Example of grid system for survey of site grounds using distances to the left or right of a baseline.

• Grid Marking and Grid Point Identification

Following the establishment of the grid system, the grid is laid out on the property, and field-marked using stakes, hubs, spikes, paint, flags, or survey tape. The selection of an appropriate marker depends on the characteristics and routine uses of the surface.

Two basic coordinate systems are used for identifying points on a grid system. The grid system shown on Fig. 4.2 references distances from the 0,0 point using the compass directions N (north), S (south), E (east), and W (west). The grid diagram designated Fig. 4.3 references distances along and to the R (right) or L (left) of the baseline.

• Grid System Examples

See the outdoor grid point and grid block identification in Fig. 4.3. The first digit or set of digits refers to the distance from the 0,0 point on the baseline and is measured in units of one hundred. The second digit or set of digits and an L or R (separated from the first set by a comma) indicates the distance from the baseline in units (ft) and the direction (left or right) from the baseline. Point A in the example of a grid system for survey of site grounds, Fig. 4.3, is identified 2+00, 100R (i.e., 200 ft from the 0,0 point on the baseline and 100 ft to the right of the baseline). Fractional distances between grid points are identified by adding the distance beyond the grid point and are expressed in the same units as used in grid dimensions. Point B on Fig. 4.3 is identified 1+30, 25R.

• Grid Block Identification

Grid blocks may be identified by choosing any one of the four corners of the grid block and using the coordinates of this corner to designate the grid block. If the grid system uses compass directions (N, S, E, W), grid blocks might be designated by calling out the coordinates of the SW corner of the block (e.g., 30N, 10E in Fig. 4.2). In a grid system using distances along and to the right or left of a baseline, blocks are identified by choosing one of the coordinates, specifying distances along the baseline and choosing the right- or left-hand corner of the block. Once a convention is established, it becomes the master identification method for the site.

• Referencing to Other Systems

Open land grids should be referenced to a location on an existing State or local grid system or to a U.S. Geological Survey (USGS) bench mark. (This will usually require the services of a professional land surveyor.)

4.2 GENERAL APPROACH

4.2.1 Scanning

Scanning is the process by which the investigator uses portable instrumentation for detecting the presence of radionuclides on a specific surface (i.e., ground, wall, floor,

equipment, etc.). A scan is performed to locate radiation anomalies indicating residual gross activity or hot-spots that will require further investigation or action, that is,

1. is the average residual activity level below the established guideline; and
2. are there small localized areas of residual activity in excess of the average guideline, (i.e., hot-spots, that satisfy the constraints applicable for such conditions)?

Experience has shown that this latter issue is often inadequately addressed. Smaller areas of residual activity typically represent a very small portion of the site, and random or systematic measurements or sampling on commonly used grid spacings have a very low probability of identifying such small areas. For this reason scanning is used to locate areas of activity that are above ambient or general site levels before static measurements or samples are collected. The scanning technique should employ the most sensitive instrumentation that is suitable for field use. The type of measurement, suitable portable instrumentation, and specific methods to perform the measurements are selected by the individual investigator and designated in the survey plan as dictated by the type of radioactive contamination present, the instrumentation sensitivity requirements, and the degree of surface coverage needed to meet the survey objectives (see Sect. 5). Scans are conducted for all radiations potentially present (alpha, beta, and gamma radiations) based on the operational history and surfaces to be surveyed. Monitoring for the unexpected is recommended. For instance, the presence of radionuclides in concentrations well above guidelines in subsurface soil may be indicated during a general scan showing only a small, localized increase in elevated radiation levels.

• Action Levels

Usually, a surveyor will investigate any anomalous reading that is recognized as being greater than the background response of the detection system. As such, the sensitivity of the scanning method will determine what level of activity can be detected. Guidance is provided in Sect. 5.3 for estimating scanning sensitivities for portable radiation detection systems. Action levels are typically used only in cases where one wants to stop and investigate countrate levels that are significantly above the background detector response. Action levels are determined prior to performing a scan survey on the basis of the potential contaminant and the detector and survey parameters. The action level is the count rate at which the surveyor should flag a localized area during a scan survey. The action level, in units of cpm, is estimated by use of the following calculation:

$$\text{Action Level} = G \times c \times E \times$$

where

G = cleanup guideline (derived concentration guideline [DCG]),
c = user selectable multiplier. For example, if the surveyor wants to mark all areas that equal or exceed 50% of the DCG, then c would be equal to 0.5,
E = detection efficiency in units of cpm per "DCG unit." Example, if the DCG is 5000 dpm per 100 cm^2, then the "DCG unit" would be dpm per 100 cm^2

and the detection efficiency used in the equation would need to be stated in "cpm per dpm per 100 cm^2."

As mentioned above, action levels as defined in the above equation are usually not used when surveying for small amounts of activity where the expected detector response is near background. Depending on the parameters discussed in Sect. 5.3.2, a small increase in the detector response above background will usually be the trigger that causes an investigator to stop and investigate further. Therefore, for most cases, the action level will be equal to the detection limit of the scanning technique as discussed in Sect. 5.3.2.

4.2.2 Systematic Measurements and Sampling

Systematic samples are collected according to a predetermined pattern based on such factors as accessibility and the features of the site without regard to external radiation levels. The purpose of these measurements or samples is to provide definitive radiation levels and/or radionuclide concentrations at precisely defined locations. Furthermore, these measurements permit the calculation of average radiation levels and/or radionuclide concentrations within a given area (by averaging individual measurements or sample analytical results) for purposes of comparison with other areas or background samples, or to estimate potential health effects to people occupying that area. Systematic measurements may be performed for alpha, beta, or gamma radiation. Samples typically include soil and routine surface smears. The type of measurement or sample, suitable portable instrumentation, and specific method to perform the measurement or collect the sample are again selected by the individual investigator as dictated by the type of contamination present, the instrumentation sensitivity requirements, and the objectives of the radiological survey. Measurements are taken by placing the instrument at the appropriate distance* above the surface, taking a discrete measurement for some time interval (i.e., instantaneous, 10 s, 60 s, etc.), and recording the measurement. Collected samples are packaged, labeled, and taken to an appropriate facility for analysis. Section 4.2.4 provides information on determining the appropriate number (or frequency) of systematic samples required to demonstrate compliance.

It is mentioned in Sect. 4.4.2 that compositing certain groups of samples may be desirable. A composite sample is a sample formed by combining several individual field samples (or portions of them) into a new sample, which is thoroughly mixed before being measured (in part or as a whole). Composite samples may be used to estimate average environmental concentrations with less cost than is possible using the original individual field samples. In no case can samples be composited over an area greater than that given in the relevant guideline. Hot spots may never be included in compositing samples for comparison to guidelines. Measurements of composite samples may also be more comparable to survey measurements obtained using *in situ* radiation detectors. Compositing must be used with care as compositing may average out (mask) small areas that have high concentrations. Also, measurements of composite samples may not be

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*Measurements at several distances may be needed. Near-surface measurements provide the best indication of the size of the contaminated region and are useful for model implementation. Measurements at 1 m (3.25 ft) provide a better measure of potential direct external exposure.

comparable to measurements of individual (uncomposited) samples or of composite samples of different sizes. The numbers and sizes of individual samples may be determined on the basis of cost and the precision desired in the estimated average. Additional information on compositing methods is provided by Boswell et al. (1992), Gilbert (1987), Gilbert and Simpson (1992), and Neptune et al. (1990).

4.2.3 Biased Measurements and Sampling

At locations where anomalous radiation levels are observed or suspected, biased radiological measurements and samples may be taken ("biased" indicates that the locations are not chosen on a random or systematic basis). The purposes of these measurements and samples are to further define the areal extent of potential contamination and to determine maximum radiation levels within an area. Biased measurements may include alpha, beta, or gamma radiations; however, at these locations measurements may also be supplemented with other types of atypical measurements such as radon flux or gamma spectroscopic measurements. Air, water, soil, and smear samples may typically be taken at these locations; samples of vegetation or sediment samples may be appropriate. All sample and measurement locations and results are recorded.

4.2.4 Systematic Sampling/Measurement Grid Frequency

The goal of systematic sampling is two-fold: (1) to collect sufficient information to demonstrate compliance with applicable average cleanup guidelines across entire survey units, and (2) to prove that small areas of contamination, which are not detectable during walk-over scan surveys, do not exceed any applicable limits.

The first of these goals is largely subjective and requires professional reasoning about the capabilities of direct measurement techniques and the costs associated with sampling, direct measurements, and laboratory analyses. A minimum amount of data must be collected to prove compliance; however, additional data may be justified if the cost is insignificant relative to other expenses. As an example, suppose that the maximum averaging area, or survey unit size, is 100 m^2 and that all localized soil contamination limits can be detected by using portable instrumentation. Given this scenario, a minimum of one sample would need to be collected from each survey unit (i.e., every 10 meters). The single samples would be used to document observed values from within each grid block. In addition, all anomalies detected while performing the walk-over scans would need to be sampled (biased sampling).

Limits for localized distinctly elevated activity levels (hot spots) will often be included as part of site cleanup guidelines. As such, the question arises as to how many samples/measurements must be taken at a site and at what frequency, or interval, they should be collected. For nuclides which cannot be detected with portable instrumentation, a sampling plan can be constructed purely by statistical analysis. However, nuclides which can be detected by field measurements add a new dimension to the problem since some level of the nuclide may possibly be detected using portable instrumentation.

Ultimately, it is the responsibility of personnel actually planning a survey to determine what sampling or measuring frequency is required at a site. The following information has been compiled to aid in this process and is presented here with an example using the information.

Statistical Grids. Table 4.1 lists the grid sizes that would be required to detect contaminated circular spots at different confidence levels. The table was compiled using the computer code Ellipgrid-PC (Davidson 1994). The following assumptions were made when tabulating the information:

- The grid was assumed to be laid out on a square with the length of each successive interval being equal to the width. The grid size denotes the distance of each successive sampling or measurement interval.
- The contaminated areas being sampled/measured were assumed to be circular.
- One sample/measurement will be collected in each grid block (i.e., grid size is synonymous with sampling/measurement).

Table 4.1. Grid size required to detect contaminated circular spots
at varying confidence levels[a]

Spot size	Probability of detecting spot			
(m²)	95%	90%	80%	60%
0.01	0.1	0.11	0.12	0.14
1	0.93	1.0	1.1	1.3
3	1.6	1.8	1.9	2.2
10	3.0	3.2	3.5	4.0
25	4.7	5.1	5.6	6.5
50	6.7	7.2	7.9	9.1
100	9.4	10	11	13
200	13	14	16	18
500	21	23	25	29
1000	30	32	35	41

[a] The grid was assumed to be laid out on a geometric square with the width interval being equal to the length interval. The grid size value denotes the distance between each successive sampling/measurement point measured both along and across the grid. *Source:* J. R. Davidson, *Ellipgrid-PC: A PC Program for Calculating Hot Spot Probabilities,* ORNL/TM-12774, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab. , 1994. All values have been rounded to two significant digits.

Field Measurements. If the nuclide of interest can be detected with portable instrumentation, then it may be possible to reduce the number of samples required at a site. In order to analyze the effectiveness of field screening with portable detectors, one

must first determine what level can be detected and with what probability. Once the detection level for a nuclide has been determined, it must then be compared to the site guideline values for that nuclide. If the guideline value can be seen *in situ* with the detection system, then the sampling/measurement frequency may possibly be reduced.

There are two common methods for using field instrumentation for sample/measurement frequency reduction. The first uses systematic measurements at a fixed interval across the suspect area. This method is generally acceptable for the detection of areas of uniformly distributed contamination. The measurements may be made on the same grid that would be required by a statistically based sampling/measurement plan or possibly on a smaller grid if additional costs are low. Use of this approach will require an evaluation of detection sensitivities for the radionuclide(s) of interest in or on the media being measured. Guidance for evaluating static detection sensitivities is presented in Sect. 5.3. Of particular importance, as is discussed in Sect. 5.3, is the natural difference in background between measurement points. This fluctuation can be significant and tends to diminish the detection ability of portable instrumentation when compared to estimates obtained in a laboratory.

The second method involves continuous scanning across the entire area of interest. The scanning usually covers 100% of the area and has the benefit of not only allowing the location of areas of uniformly distributed contamination, but also allowing the detection of localized spots of contamination. Section 4.2.1 contains information related to general approaches for scanning. Section 5.3.2 provides guidance on evaluating scanning detection sensitivities.

Either of these two methods or a combination of the two can be very useful for reducing the number of samples or measurements required at a site and thereby reducing the total cost of a field survey. It should be stressed that field screening methods be used with prudence. A misapplication of *in situ* methods could result in a contaminated site being assessed as clean if the investigative team does not truly understand the capabilities or limitations of the instrumentation being used.

Example:

A site with ^{137}Cs contamination in the surface soil has a derived cleanup guideline (DCG) of 2 pCi/g above background averaged over a maximum of 100 m^2 of land area. The guideline structure being used at the site allows small areas to have higher contamination levels, but the amount allowed within any single localized area is limited by multiplying the average DCG of 2 pCi/g by an appropriate factor as indicated in the following table:

Relationship of allowable residual contamination
to size of spot

Area of spot (m²)	Factor (multiple of limit)	Resulting allowed concentration (pCi/g)
<1	10	20
1 - <3	6	12
3 - <10	3	6
10 - 25	2	4

The investigators estimate that by using a specific type of NaI detection system, small areas of 1 m² or larger with an average surface activity (top 6 inches) of approximately 5 pCi/g can be detected by performing a slow, walk-over surface survey. Additionally, it is determined that when taking 1-min static timed counts with the same detectors, the detection limit will be around 2 pCi/g. Referring to the multiplication factors listed in the above table, it can be seen that all elevated areas from 1 to approximately 9 m² can be detected with a walk-over scan-type survey. Therefore, areas of 10 m² and larger must be detected by sampling or by fixed-point static measurements. Samples must be collected to ensure that any remaining localized contaminated areas within the survey site are detected. Referring to the table above, a sample grid size of 3 meters will give a 95% probability of hitting 10-m² circular areas within the survey site. Likewise, a sample frequency of 1 in every 5 meters will provide a 90% to 95% probability of detecting 25-m² areas.

Given this scenario, a plausible approach would be to: (1) perform a walk-over survey of the entire area using portable detectors, (2) collect static timed measurements with portable detectors on a grid spacing of 3 meters to ensure detection of the 3- to 25-m² areas, and (3) collect samples on a grid spacing of one in every 10 meters to ensure detection of 100-m² areas. Any anomalous readings noted during either the scan or the fixed-point measurements would necessitate the collection of a sample at these locations. Also, please note that to truly show compliance with the stated DCG, which allows averaging only over 100-m² areas, at least one sample should be collected for every 100–m² area regardless of *in situ* detectability.

4.3 RADIATION MEASUREMENTS

When using portable field instrumentation to measure surface contamination for alpha and beta emitters on structures and items, it is important to recognize the effects of various conditions on the detection efficiency of the instrumentation being used. The presence of covering materials or the diffusion of the contaminant into the surface being

evaluated can result in true detection efficiencies that are significantly different from those observed on calibration sources in a laboratory. Generally, the influence of such conditions on the detection efficiencies will be variable across any given surface at a site. Since the magnitude of such factors can be significant yet inconsistent between measurement points, professional judgement must be relied upon. A good understanding of detector capabilities and of geometry and shielding effects for the radiation(s) of interest is required when evaluating the impact of real measurement conditions on detection efficiencies.

The following guidelines can be used both when planning and performing radiation measurements for surface contamination with portable instrumentation. The list is intentionally brief, and by no means should one exclude alternate approaches that are technically valid.

- Significant amounts of material that have been added over the contamination since the material was originally deposited should be removed prior to actually performing measurements. "Significant" should be interpreted to mean that the expected detection efficiency will be affected by more than 30%. If the radionuclide can be detected through the covering with an acceptable sensitivity level and removal of the covering material is deemed unnecessary, then the effect of such coverings on the detection efficiencies should be accounted for by use of an appropriate correction factor.

- In the case of pure alpha emitters or very low beta emitters on aged, very porous, dirty, painted or otherwise coated surfaces it is often not possible to detect the contaminant. In these cases, samples and transferrable swipes should be collected to supplement direct measurements. See Sect. 4.4 for a discussion of sampling and swipe techniques.

- If the contaminant has significantly migrated into the media or if the contaminant is an activation product within the media, then surface release criteria will usually not be valid. Alternate, dose-based-concentration release criteria should be developed using reasonable exposure scenarios.

4.3.1 Alpha Measurements

Indoor alpha measurements should include the following when applicable: systematic measurement of surface alpha activity on walls and floor surfaces, measurement of alpha activity at locations of elevated gamma or beta radiation levels (when the contaminant is both an alpha- and beta-emitter), and measurement of alpha activity on potentially contaminated equipment surfaces. Section 5.3 contains guidance on determination of detection sensitivities.

• Scanning

Because alpha radiation has a very limited range, special attention is required regarding the distance the instrument is held from the surface and the speed with which it is moved. The scanning detector is held at less than 1 cm (0.39 in.) from the surface,

and is moved at a rate such that the surface guideline level can be seen with some level of certainty.

• Static

To conduct direct measurements of surface alpha activity, instruments and techniques providing the required detection sensitivity are selected. Experience has shown that a 1-min integrated count technique, using a large area [>50 cm² (8 in.²)] detector, is a practical field survey procedure and will provide detection sensitivities that are below most guideline levels. However, under certain circumstances, longer or shorter integrating times may be warranted (see Sect. 5).

4.3.2 Beta Measurements

Indoor beta measurements should include the following when applicable: anomalies, systematic locations [a minimum of one measurement for each 1 m² (10.8 ft²) for current release guidelines],* specific locations where contamination by beta-emitting radionuclides is suspected, locations where gamma-ray exposure rates are significantly elevated, and measurement of beta activity on selected equipment surfaces.

Instruments and techniques providing the required detection sensitivity are selected to conduct direct measurements of surface beta activity (for discussion of instrument selection, see Sect. 5). Section 5.3 provides additional information on the evaluation of detection sensitivities.

• Scanning

Because beta radiation has a limited range, a relatively low count rate may represent the presence of contamination above the guideline. The relationship between size of the detector surface, the distance from the surface being measured, and the speed of movement of the detector over the surface should be adjusted to ensure detectability. Typically, the beta radiation scanning detector is held at less than 2 cm (0.8 in.) from the surface and moved across the surface at a rate such that the surface guideline level can be seen with some level of certainty.

• Static

Surface activity measurements are performed at systematically and randomly selected locations and at locations of elevated direct radiation identified by surface scans. A 1–min integrated count technique using a large area [>50 cm² (8 in.²)] detector is a practical field survey procedure and will provide detection sensitivities that are below most guideline levels.

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*If the scanning technique employed can detect less than 50% of the guideline value (when a guideline value is available) then the minimum number of measurements may be reduced to 1 per 2 m². Again, these default values assume that the current release guidelines shown in Appendix A are being applied.

4.3.3 Gamma Measurements

External gamma radiation measurements are sometimes made to evaluate potential personnel exposures, and to provide a radiation "map" to assist in planning and implementation of subsequent remedial action. These radiation measurements can include the following:

1. Gamma radiation measurements at near contact with the ground surface and at 1 m (3.25 ft) above ground; average and maximum measurements for both indoors and outdoors can then be determined.
2. Surface gamma-ray scanning to identify radiation anomalies and to define the areal extent of above-background radiation exposures.
3. Surface gamma-ray scanning of equipment and other materials at the site where appropriate.
4. Pressurized ionization chamber (PIC) measurements at locations of differing gamma radiation spectra. Since NaI detectors are very energy dependent, exposure rate measurements with both a PIC, or equivalent, and a NaI detector can be used to correlate the NaI response to the actual exposure rate. Essentially, a site-specific correction factor is determined by collecting paired measurements at points of different exposure rates. See Sect. 5.5, Instrument Calibration and Response Check.

• Scanning

A NaI scintillator is normally used for gamma scanning. The detector is held at near contact [6 cm (~2 in.)] with the ground surface and moved in a serpentine pattern while walking at a speed of about 0.5 m (1.5 ft) per second. For ease of detection, changes in the instrument response are monitored via the audible output using headphones rather than by noting fluctuations in the analog meter reading. Actual measurements for all areas, including background as well as anomalous readings, should be recorded. Locations of direct radiation exceeding the action level are marked on facility maps and identified for further measurements and/or sampling (see "scanning" above). Section 5.3.2 provides further discussion concerning evaluations of scanning sensitivity.

• Static

Gamma radiation measurements are made at near contact with the ground surface and at 1 m (3.25 ft) above the ground at systematic locations, and at locations of elevated radiation identified by area gamma scans. Some limited sampling or the use of gamma spectroscopy will be required to identify the radionuclide and to determine if the residual activity is distributed in the surface layer of soil or subsurface layers. Portable gamma spectrometers allowing on-site radionuclide identification may be useful. Measurements at 1 m will not be necessary if external exposure rates do not need to be measured.

4.3.4 Subsurface Measurements (Subsurface Hole Logging)

Logging of bore holes is performed to identify the presence of subsurface deposits of radionuclides. This information helps to guide subsurface sampling efforts. Auger holes and core holes are evaluated (logged) using a probe designed to detect the radiation associated with the contaminant of interest. Although the most common application is to measure the relative gamma-fluence rate versus depth using a NaI detector, beta measurements with thin-window GM-type detectors can be made if there is no water in the auger hole. For gamma measurements, a plastic pipe (e.g., PVC schedule 40) large enough to accommodate the detector can be placed in a bore hole to both prevent wall erosion and to displace water when present. A radiation detector is lowered inside the pipe and measurements are usually made at 15- or 30-cm intervals. The probe can be encased in a lead shield with a horizontal row of collimating slits on the side. This collimation allows measurement of gamma radiation intensities resulting from contamination within small fractions of hole depth. Unshielded NaI detectors may also be used to detect the presence of elevated levels of gamma radiation, but the depth profile will not be nearly as exact.

Logging techniques are not normally radionuclide specific. However, logging data in conjunction with the soil analysis data may be used to estimate regions of elevated radionuclide concentrations in auger holes when compared to background levels for the area. If radionuclide identification is desired, a portable multichannel analyzer (MCA) coupled to the detector may provide this information.

4.4 SAMPLING

4.4.1 Removable Activity (Smears)

Smears, also known as swipes, provide a semi-quantitative measure of removable activity and are obtained by wiping an area using a dry filter paper while applying moderate pressure. The area of concern for smear surveys will usually be 100 cm² (15.5 in.²) since current surface contamination guideline values (see Appendix A) are specified in terms of this areal size. If a different area is swiped, as for objects with a smaller surface area, the results should be corrected back to the same area as specified in the surface contamination guideline. If the surface is thickly coated with particulate material, such as rust or dirt, a sample of the particulate material should be collected as a separate sample instead of attempting to use a smear.

Dry paper filters with diameters ranging from around 30 mm up to 50 mm are typically used for smears, although fabric materials have been growing in popularity as the material of choice. For surveys of small penetrations such as cracks or anchor-bolt holes, moistened cotton swabs may be used to wipe the area of concern. Moistened paper swipes may be used to collect tritium from dry surfaces, but dry swipes should be used when the surface is damp. Materials that dissolve well in solvent-based scintillation cocktails, such as styrofoam, are also used by some for collecting tritium

swipes. "Sticky" smears may be necessary under certain conditions such as a surface consisting of dry particles. Smears are placed into envelopes or other individual containers to prevent cross-contamination while awaiting analysis.

It is unlikely that outside surfaces, exposed to wind and rain, will have significant levels of removable surface activity. If removable activity is suspected, smears or swabs may be obtained and analyzed as described in Sect. 6. Smears for removable surface activity are not appropriate for use on soil.

4.4.2 Soil

Both biased and systematic outdoor samples should be obtained and analyzed to determine soil radionuclide concentrations. Samples collected according to a predetermined pattern based solely on such factors as accessibility and the features of the site and without regard to external radiation levels are called "systematic samples." (See Sect. 4.2.4 for discussion concerning Systematic Measurement/Sampling Grid Frequency.) Systematic samples must also be relied upon where alpha and/or beta radiation is found in the absence of gamma radiation. "Biased samples" are those obtained at locations showing elevated radiation levels and/or from locations of known soil contamination. The potential necessity for archival and storage of soil and other environmental samples for indeterminate periods of time, and the constraints this may place on resources and handling may be a consideration in selection of sampling procedures.

Many soil release criteria are specified for fixed increments of depth relative to the soil surface. When performing excavations, it can become difficult to determine what elevation should be considered zero depth since the excavation process often becomes quite large and complex. Lacking guidance to the contrary, zero depth for soil samples, (i.e., the soil surface) should be considered equivalent to the top of the final grade soil level post-remediation.

• Surface

Surface soil samples are collected from the top 15 cm (6 in.) of soil or in accordance with the site cleanup criteria, if different. Sample size should be consistent with requirements of the analytical method. For example, 1-kg samples provide adequate media for gamma spectrometry analysis of intermediate- to high-energy gamma-emitting radionuclides. The possibility of compositing certain groups of samples should also be considered when determining the quantity of sample to be obtained. Sampling may be conducted using a variety of simple hand tools, such as a shovel, trowel, or "cookie-cutter" tool. Samples should be representative of a known surface area. Sampling tools are cleaned and monitored, as appropriate, after each use.

If there is a potential for soil activity beneath paved surfaces, the surface can be removed by coring and the underlying soil sampled as surface soil.

• Subsurface

Subsurface investigations consist of measurements and samples taken beneath the ground or floor surface. The purpose of these investigations is to locate and define the vertical extent of the contamination. These investigations are conducted by excavating the floor or ground surface (by trenching, augering, coring, shoveling, or other means) to depths that are below contaminated soil. These depths are controlled by several factors and must be determined during the logging/sampling procedure (see Sect. 4.2.4). It may be possible to determine the maximum drilling depth from field measurements or by excavating to undisturbed soil. The environmental conditions at some depth may appear to prevent further downward migration of contaminants; thus, no further drilling may be required. In other instances, it may be necessary to rely on the results of laboratory analyses of samples because some radionuclides are not detectable with field instrumentation.

Consideration should be given to the possible presence of structures such as buried "live" power lines or pipes when conducting subsurface investigations. A facility engineer should be consulted when available.

Filled areas, buried piping and underground tanks, spills, and septic leach fields that may have received contaminated materials are locations that may require sampling of subsurface soil. The need for special sampling by coring or split-spoon equipment,* usually by a commercial firm, should be anticipated.

Excavated material or material from the sides of the vertical walls, and water or air in the excavated hole may be sampled for radionuclide analyses. The number of excavations and the type of measurements or samples to be obtained and appropriate procedures to be used will be determined by the type of contamination present, limitations in field conditions, and objectives of the survey plan.

Subsurface soil may be sampled using portable manual equipment or, if the sampling depth is greater than several meters, heavier truck-mounted sampling rigs. For shallow subsurface sampling, the hole is advanced to the desired starting depth, using a post-hole digger, shovel, twist auger, motorized auger, or punch-type Shelby tube sampler. Loose material is removed from the hole and the sample collected over the next 15- or 30-cm (6- or 12-in.) depth. Continuous coring samplers or barrel samplers, advanced through hollow stem augers, are usually used for obtaining deeper subsurface samples. The entire core can be retained and monitored intact to determine if layers of activity are present, or sections of the core can be removed for analysis. Unless there is prior information regarding the depth and distribution of subsurface activity, samples should be obtained at approximately 1-m (3.25-ft) intervals (or smaller if necessary for guideline compliance) from the surface to below the suspected depth of the residual activity.

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*A "split-spoon" (or "split-barrel") sampler is constructed in such a way as to allow the collection of samples from relatively precise and determinable locations within a hole with little possibility of contamination by soil from other depths of the hole. The split-spoon tool is available in various sizes and lengths, and is pipe-shaped in appearance. Soil fills the "pipe" as it is driven into the ground and is prevented from loss by a flanged basket device as the tool is withdrawn. The sampler "splits" vertically in half for sample removal. Samples collected in such a manner may also be called "core" samples.

Many States and local governments have regulations restricting the drilling of boreholes and requiring special handling of drilling spoils and back-filling of holes. Investigators should consult these agencies before initiating subsurface investigations.

4.4.3 Water

Water samples from the site and surrounding area should be obtained and analyzed when necessary. Depending on the site, water sources may be rivers, streams, lakes, potable water, wells, etc. Water found in any drill hole can be sampled as is, filtered if necessary, acidified on-site after filtration, and both fractions (filtrate, suspended solids) analyzed. Since water samples must be returned to the laboratory for analysis, it is important to preserve the original concentrations of the radionuclides before analysis. Follow laboratory instructions for any required pretreatment. Additional guidance relating to environmental sampling and analysis of surface water, drinking water, and ground water is provided in Chapter 5 of DOE/EH-0173T, January 1991 (DOE 1991a).

Water samples usually range from 1- to 3.5-L in size depending on the analytical procedure to be used and depending on the number of separate analyses or individual radionuclides to be determined. It may be prudent to coordinate sampling methods with the limitations and requirements imposed by the analytical laboratory of choice. Re-use of sampling equipment requires careful rinsing techniques to prevent cross-contamination.

Example equipment includes:

        a. polyethylene bottles with caps,
        b. plastic funnel,
        c. filter paper to fit funnel,
        d. waterproof ink marking pen, and
        e. ladle or sample scoops
        f. sample labels.

Surface water samples can be collected by dipping polyethylene bottles directly into the water body if the water is deep enough, rinsing the bottle first with the water to be sampled. A cloth filter will prevent the collection of solids. Use of the ladle or scoop and funnel will allow collection of water samples from shallow sources. Subsurface water samples may require on-site improvisation by the team members depending on the depth and diameter of the access hole.

4.4.4 Air

If conditions at the site suggest the potential for airborne contaminants, radionuclide concentrations in air should be determined at the locations where these conditions exist. Air sampling for radionuclides typically begins with an initial screening for gross alpha and gross beta-gamma activity. The most common procedure for the collection of air samples is to draw air through a filter paper and analyze the collected particulates for

radioactivity. Gross activity measurements indicate the need for specific radionuclide identification. If airborne activity other than particulates (i.e., gases such as ^{3}H) is probable, specialized procedures for the collection and analysis of the contaminating radionuclides will be required.

Tables 5.1 and 5.2 (Sect. 5) provide information regarding instrumentation for the counting of air samples. Air-filter samples containing radionuclides associated with aerosol particles can be counted directly without any chemical separation. However, high flow rates, fibrous filters, and chemical separation processes are necessary to count low concentrations of alpha emitters. Chemical separation is also generally required for small concentrations of low-energy beta-emitters. Alpha activity can be measured directly from fibrous filters with alpha spectrometers providing deposits are not too thick and interfering radionuclides are not present. The measurement of many radionuclides on air-filter samples can be seriously affected by high concentrations of naturally occurring short-lived radon and thoron decay products. The passage of several hours or days may be required to allow the decay of all radon and thoron progeny. Additional precautions and pitfalls relating to general air sampling as well as to sampling of particulates, radioiodines, noble gases, or tritium are provided in DOE/EH-0173T (DOE 1991a).

4.4.5 Radon

At sites at which progeny of the uranium, thorium, and/or actinium decay chains occur (^{226}Ra, ^{228}Ra, ^{227}Ac), it may be necessary to sample for radon and radon daughter concentrations in air. Radon and radon daughter measurements may be taken by a variety of methods, over various time intervals, using instrumentation specific to the radionuclide involved and survey objectives. A technique for the simultaneous measurement of daughters of ^{222}Rn, ^{220}Rn, and ^{219}Rn in air is presented in Perdue et al., 1978. Section 5.6 provides a more detailed discussion on the various procedures, instrumentation, and techniques that have been developed for measuring radon.

• Indoor

When contaminated material containing thorium, radium, or actinium has been located within, beneath, or near a structure on a survey site, instantaneous or short-term radon and radon daughter measurements should be made inside the basement and/or at ground level inside the structure. To typify radon and radon daughter concentrations, measurements are usually taken indoors in high-occupancy areas when the structure has not been deliberately vented or closed. Although individual measurement results may be reported (in a table or appendix in the survey report), indoor air concentration values are generally averaged for risk assessment. The results of these measurements will determine the need for long-term radon and radon daughter monitoring.

Pathways of radon infiltration into structures may be identified by making radon flux measurements over suspect areas (i.e., drains, floor cracks, etc.).

• Outdoor

Outdoor radon measurements are generally required if there is a significant radium source on site. This possibility should be addressed. Samples may be collected at several locations around the perimeter of the site to determine maximum mean release rates to the surrounding environment. Air measurements are needed to demonstrate compliance with DOE 5400.5. Radon flux measurements also might be required.

4.4.6 Miscellaneous

Although vegetation is not routinely obtained for analysis, collection of such samples should be made when the potential for food chain contamination justifies it. For example, if a vegetable garden has been planted over contaminated soil, vegetable samples should be obtained and analyzed. Several kilograms of vegetation may need to be sampled depending on the analytical sensitivities for the radionuclides of interest.

Samples from a variety of locations may be required, depending on the specific facility conditions and the results of scans and direct measurements. Residue can be collected from drains using a piece of wire or plumbers "snake" with a strip of cloth attached to the end; deposits on the pipe interior can be loosened by scraping with a hard-tipped tool that can be inserted into the drain opening. Particular attention should be given to "low-points" or "traps" where activity would be likely to accumulate. The need for further internal monitoring and sampling is determined on the basis of residue samples and direct measurements at the inlet, outlet, clean-outs, and other access points to the pipe interior.

Residual activity will often accumulate in cracks and joints in the floor. These are sampled by scraping the crack or joint with a pointed tool, such as a screwdriver or chisel. Samples of the residue can then be analyzed; positive results of such an analysis may indicate possible subfloor contamination. Checking for activity below the floor may require accessing a crawl space (if one is present) or removal of a section of flooring.

Grass, rocks, sticks, and foreign objects are removed from soil samples to the degree practical at the time of sampling. If there is reason to believe these materials contain activity they should be retained as separate samples.

4.5 BACKGROUND MEASUREMENTS

Many release criteria for residual radioactive materials are presented in terms of radiation levels or activity levels above background for an area or facility. As a result, background measurements are collected in reference areas to provide baseline data for comparison with measurements and data collected at a site. Background measurements and samples should be site- or area-specific—or, when surveying special material, be material-specific—and for each type of measurement a comparable reference background radiation level should be known. In some instances, background radiation

levels may be determined by consulting documented values in published reports. Environmental baseline surveys may also be useful. NUREG-1501, "Background as a Residual Radioactivity Criterion for Decommissioning" (NRC, 1994a) provides a considerable amount of information pertaining to the sources of and evaluation of radiation and radionuclide backgrounds.

Areas with a minimal probability of being impacted should be chosen for collection of background measurements. They should be determined at locations in the vicinity of the site that are unaffected by effluent releases (upwind and upstream) and other site operations (upgradient from disposal areas). Background reference locations to be avoided when possible include those that may have been affected or disturbed by non-site commercial activities, particularly those that may have dealt with the same contaminant. It may be necessary to use areas such as these when more acceptable locations are not available. The possibility that an acceptable off-site area will not be available is particularly true for sites built many years ago.

The levels of many radionuclides occurring naturally in the environment are insufficient to be quantifiable using standard measurement techniques. Those naturally occurring concentrations may also be insignificant relative to the DCGs. On the other hand, levels of direct radiation (exposure rates) and some naturally occurring (uranium and thorium decay series, and ^{40}K) or man-made (^{137}Cs) radionuclides are typically present in the environment at levels that are easily quantifiable and may have background levels that are significant relative to the DCG.

Localized geologic formations, different types of soil, and construction materials at the background measurement locations may result in background values that have greater variability. Consequently, the number of measurements required to ensure a representative average value is dependent on specific site conditions. Large sites with complex geology may require separate background determinations for selected areas of like geology and soil type. Soil moisture, for example, can account for 30% of the soil mass during wet periods and can significantly affect results when making gamma-fluence rate measurements. An underlying layer of "Chattanooga shale" containing elevated concentrations of natural uranium may enhance both the soil concentrations and the surface exposure rate. Igneous rock contributes less radionuclide content to soils than does sedimentary rock because, although it is high in radioactive content, it weathers more slowly than the softer sedimentary rock (Eisenbud, 1980).

Background levels for indoor measurements may differ from those in open land areas because construction materials often contain naturally occurring radioactive substances that can provide a shielding effect. Preferable locations for interior background determinations are within buildings of similar construction, but having no history of involvement with radioactive materials. Since the amount of naturally occurring radioactivity varies with material type, the background levels for specific materials being surveyed should be evaluated when necessary. Masonry brick, for example, often contains elevated levels of naturally occurring ^{232}Th, ^{238}U and ^{40}K. The presence of naturally occurring radioactive materials will cause an increase in the count

rate from most beta and gamma detectors. As a result, slower scanning rates will be required, and the possibility of detecting a contaminant at the DCG may even be prevented.

Total radiation or radioactivity levels measured in each survey unit will be compared to background values obtained. Therefore, the background levels should be determined with an accuracy at least equivalent of the data to which it will be compared. This can be achieved by using the same instruments and techniques for background surveys as are used in assessing site conditions. The background radiation measurements should be presented in the survey report and should be discussed in the results.

The procedure for testing the data and determining the number of additional samples and/or measurements needed is described as follows.

• Determining Numbers of Background Data Points

The number of measurements and samples required to determine a representative average value is dependent on specific site conditions. For example, large sites with complex geology may require separate background determinations for selected areas of like geology and soil types. There are no specific rules for determining the minimum number of background measurements and samples of each type, except that the number should be large enough to adequately depict the true underlying distribution of values.

For cases when the average background is insignificant relative to the DCG, an initial 6 to 8 measurements or samples will typically be adequate for evaluating the background radiological conditions. If the upper 95% confidence level bound on the background average is less than 10% of the guideline value for that parameter, variations in background may be considered insignificant and no further determinations are necessary. However, if the upper 95% level bound on the background average is greater than 10% of the guideline, the background data should be tested to ensure that the average represents the true mean to within ± 20% at the 95% confidence level. If necessary, additional background determinations should be performed to satisfy this level of representativeness. Selection of this criteria for defining an acceptable accuracy for background determinations is arbitrary, based on the natural variations (of background levels) occurring in the environment and the need to keep the effect and cost directed to background determination reasonable.

The total number of determinations needed to satisfy the objective is calculated by
(4.1)

$$n_1 = \left[\frac{t_{95\%df} \cdot s}{0.2 \cdot \overline{x}} \right]$$

where

n_1 = number of data points required,
$\overline{x}$ = mean of mutual determinations,
s = standard deviation of initial measurements,

$$t_{95\%,df} = t \text{ statistic for } 95\% \text{ [or } 90\% \text{ } (t_{90\%,df})] \text{ confidence at}$$
$$df = n{-}1 \text{ degrees of freedom where } n \text{ is the number of initial data points.}$$

Table 4.2 is a list of values for the $t_{90\%}$ and $t_{95\%}$ statistics at various degrees of freedom. Subtracting the number of data points already collected (n) from this total calculated number (n_1) determines the number of additional measurements or samples that will be required to demonstrate the desired confidence of the data. If this calculation indicates that additional data are needed, it is recommended that the data be collected uniformly over the area, using the same sampling method as that used for the initial samples. The average background is then recalculated using all data points.

Sample Calculation:

Seven soil samples collected for determining the background level of [238]U contained the following concentrations:

1.3 pCi/g (48 Bq/kg)	1.8 pCi/g (66 Bq/kg)
0.6 pCi/g (22 Bq/kg)	1.5 pCi/g (55 Bq/kg)
0.9 pCi/g (33 Bq/kg)	2.0 pCi/g (74 Bq/kg)
1.6 pCi/g (59 Bq/kg)	

The mean and standard deviation for these data are calculated to be 1.39 pCi/g (51 Bq/kg) and 0.5 pCi/g (18 Bq/kg), respectively; the $t_{95\%}$ statistic (Table 4.2) is 1.943 for 6 degrees of freedom. The total number of determinations required to establish the average background to within ± 20% of the true average at the 95% confidence level is calculated by

$$n_1 = \left[\frac{1.943 \bullet 0.50}{0.2 \bullet 1.39} \right]^2 = 3.49 \tag{4.2}$$

Recomputing Eq. (4.1) when $df = n_1 - 1 = 12$ gives

$$n_2 = \frac{(1.782 \bullet 0.50)^2}{(0.2 \bullet 1.39)^2} = 10.27$$

which is rounded up to 11. Another iteration gives

$$n_3 = \frac{(1.812 \bullet 000.50)^2}{(0.2 \bullet 1.39)^2} = 10.62$$

which is rounded up to 11, the same n as obtained in the previous step. These calculations indicate a need for a total of 11 data points, or 4 additional data points (11–7) to satisfy the statistical objective for this case. This approach is not valid unless the background data have a normal (Gaussian) distribution, which may not be true in

Table 4.2. Factors of $t_{90\%}$ and $t_{95\%}$ for comparison of survey data with guidelines

Degrees of Freedom[a]	$t_{90\%}$	$t_{95\%}$
1	3.078	6.314
2	1.886	2.920
3	1.638	2.353
4	1.533	2.132
5	1.476	2.015
6	1.440	1.943
7	1.415	1.895
8	1.397	1.860
9	1.383	1.833
10	1.372	1.812
11	1.363	1.796
12	1.356	1.782
13	1.350	1.771
14	1.345	1.761
15	1.341	1.753
16	1.337	1.746
17	1.333	1.740
18	1.330	1.734
19	1.328	1.729
20	1.325	1.725
21	1.323	1.721
22	1.321	1.717
23	1.319	1.714
24	1.318	1.711
25	1.316	1.708
26	1.315	1.706
27	1.314	1.703
28	1.313	1.701
29	1.311	1.699
30	1.310	1.697
40	1.303	1.684
60	1.296	1.671
120	1.289	1.658
infinite	1.282	1.645

[a] For values of degrees of freedom not in table, interpolate between values listed.

Source: D. L. Harnet, *Introduction to Statistical Methods,* 2nd ed., Addison-Wesley, Reading, Massachusetts, 1975.

many situations. For that reason, the number of background samples obtained in this way should be considered a lower bound.

Basic textbooks on statistical methods such as D. L. Harnet, 1975, will provide other confidence levels if desired.

4.6 SURVEY OF EQUIPMENT AND SMALL ITEMS

Surveys for release or characterization of non-real property (equipment or other small objects and materials, and personal items) are conducted using a process similar to that used for lands and structures. Such surveys may be conducted (1) to release non-real property during decontamination and decommissioning projects or where remedial measures are being implemented, or (2) as part of a facility's normal operations. Figure 4.4 diagrams a general process for conducting these surveys and determining if the subject properties are acceptable for release.

The first step is to characterize the use of the item or equipment. If there is adequate process knowledge to certify that the item(s) or equipment was never subject to radiological contamination,* the material may be released without radiological survey. Property that may contain residual radioactive material or has been decontaminated must be surveyed before release to verify that residual radioactive material concentrations on surfaces or in the material are less than the authorized limits and comply with the ALARA process requirements. The detail and scope of the survey should be proportional to the potential for contamination. The limits should be applied and release approved on the basis of the following conditions:

a) Prior to release, property should be surveyed to ensure that the limits and ALARA objectives have been achieved.

b) Survey techniques and instruments are appropriate for detecting the specific limits.

- Direct measurements and swipes/samples should be taken so that applicable release criteria are evaluated.
- Samples should be taken if the property may be contaminated in volume.

c) Surveys, analyses, and evaluations shall be conducted by qualified personnel.

As Fig. 4.4 indicates, the process allows flexibility with regard to authorized limit development. In those cases where there are a significant number of items or pieces of equipment to be released and some above background levels of residual radioactive

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*``Property shall be considered to be potentially contaminated if it has been used or stored in areas that could contain unconfined radioactive material or that are exposed to beams or particles capable of causing activation (neutrons, protons, etc.),'' Order DOE 5400.5, February 8, 1990. It is noted that items stored out of the radiation control area are not considered subject to activation due to the relatively low intensity of the beams permitted in uncontrolled areas.
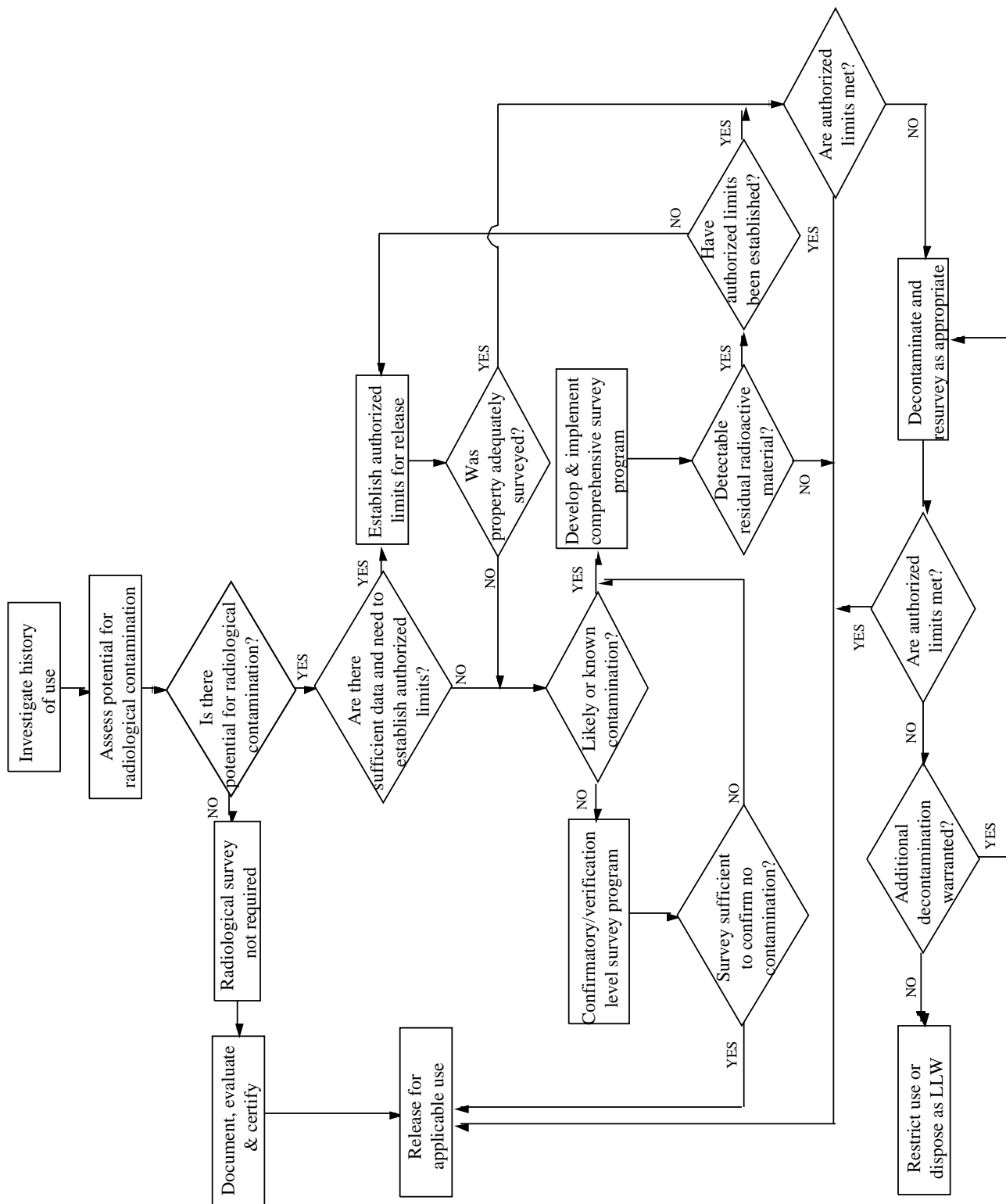
Fig. 4.4. General process for surveys for release or characterization of non-real property.

material are likely to be encountered, authorized limits (consistent with the ALARA process) should be established prior to the survey. This will permit the development of a more specific survey plan or protocol and more efficient surveys. However, the establishment of such limits may require considerable effort (to complete the ALARA analysis) or may require more information than is available with regard to radionuclide mix and distribution. Therefore, if it is expected or there is reasonable expectation that the item(s) is not contaminated, establishment of authorized limits may be deferred until such time as it is clear they are required. If surveys are conducted prior to development of authorized limits, any detectable residual radioactive material will necessitate the development of authorized limits. Figure 4.5 provides more specific information for the survey process when it has been determined that the property cannot be released on the basis of process knowledge. At this point in the process the property can be categorized as either:

Category 1 – contaminated, previously contaminated, or highly suspect, requiring comprehensive or full survey (similar to the character-ization or final release survey for lands and structures), or

Category 2 – possibly contaminated with no direct evidence of contamination, requiring at least a confirmatory/verification-type survey.

Property known to be contaminated or believed contaminated, or property that has been decontaminated should receive comprehensive surveys before release. Property or equipment previously decontaminated for which radiological data are incomplete, or not completely adequate, also qualifies for Category 1 treatment. All surfaces should be scanned, smear-sampled, and a sufficient number of static counts completed to ensure that the property meets the applicable release criteria. In most cases, scans for hot spots should cover nearly 100% of the accessible surfaces and systematic static measurements should be completed. Systematic measurements should be proportional to the size of the items being surveyed and should be no less frequent than one per square meter of surface. However, static measurement frequency may vary depending on the detection limits of the scanning. If the scanning sensitivities are good (activities of less than 50% of the authorized release limit), static measurements may be less frequent and may be performed only for confirmatory/verification measurements. However, if the sensitivity for scanning is significantly above the release limits [e.g., 3 times the limit for average activity) a statistically valid number of static measurements must be made [see DOE/CH-8901 (DOE 1989a)]. In addition, difficult-to-access areas that are subject to contamination should be surveyed to obtain a representative estimate of residual radioactivity. This may require disassembling significant portions of the equipment. In some cases, a less comprehensive survey may be permitted if property-specific conditions are such that selected scanning, static measurements or samples/swipes of specific portions of the equipment, item, or property provide confidence that the unsurveyed portions of the item of interest are not contaminated. For example, if mea-surements of representative lengths of ducting or pipes, and measurements in traps or at elbows demonstrate no levels of radiation above the limits, and concentrations of radionuclides in fluids contained in the pipes or equipment are not indicative of
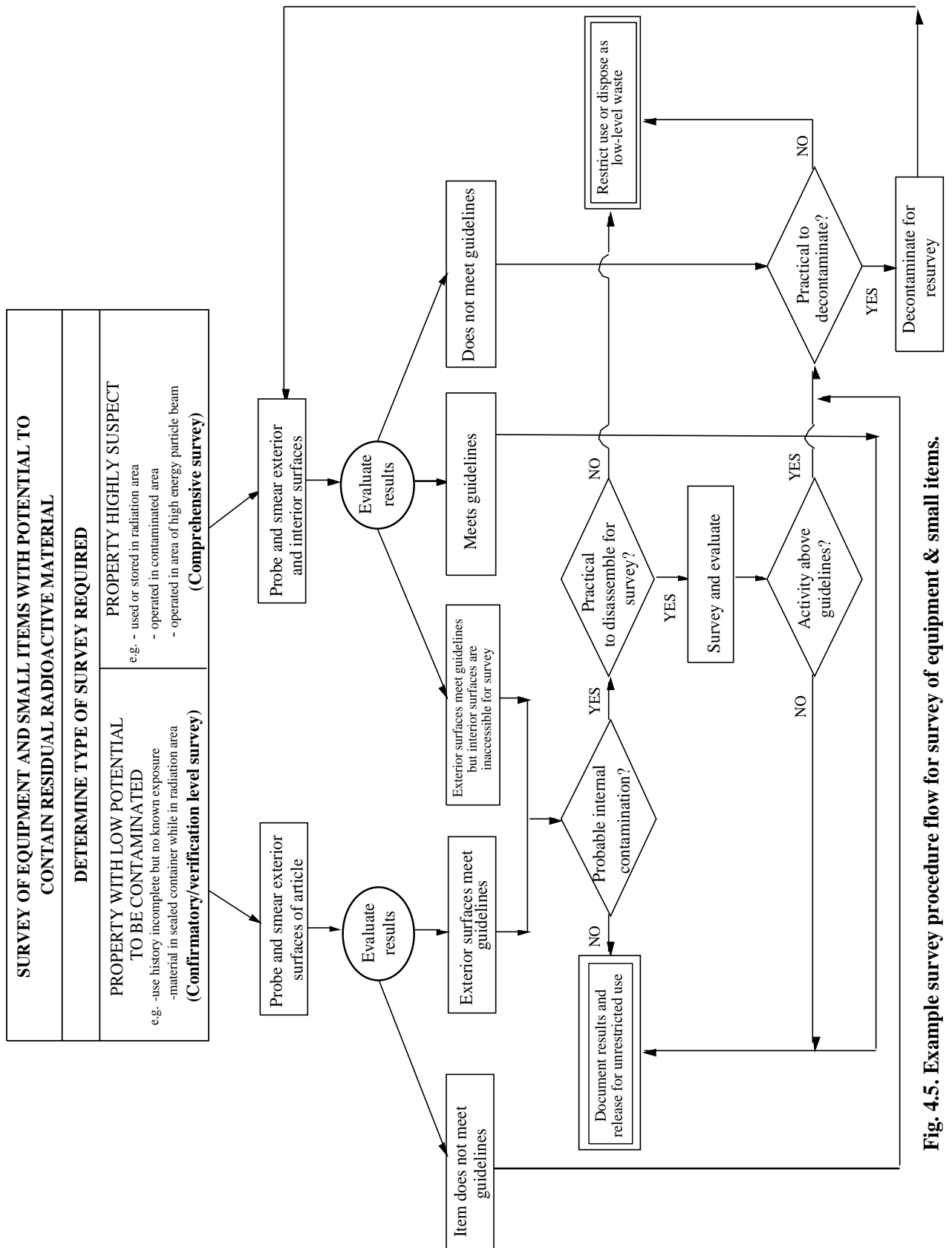
SURVEY OF EQUIPMENT AND SMALL ITEMS WITH POTENTIAL TO CONTAIN RESIDUAL RADIOACTIVE MATERIAL

DETERMINE TYPE OF SURVEY REQUIRED

PROPERTY WITH LOW POTENTIAL TO BE CONTAMINATED

e.g. - use history incomplete but no known exposure
- material in sealed container while in radiation area
(Confirmatory/verification level survey)

PROPERTY HIGHLY SUSPECT

e.g. - used or stored in radiation area
- operated in contaminated area
- operated in area of high energy particle beam
(Comprehensive survey)

Fig. 4.5. Example survey procedure flow for survey of equipment & small items.

contamination, the property may be released without surveying 100% of the material. When this representative sampling/survey approach is applied, the survey leader should select, for survey/sampling, those areas or portions of the item(s) being evaluated for release that are most likely to be contaminated. Data collected using the representative sample/survey approach should be analyzed to show that there is a 95% significant confidence that the areas sampled are within guidelines. However, the "representative sampling/survey" approach should only be used when there is significant benefit from doing so, or when a full survey is not physically possible. A full survey is recommended when the subject property is highly suspect, known to be contaminated or potentially contaminated, and easily accessible.

The second category described above covers items or equipment where there is low potential for contamination (contamination is possible but unlikely). These items may have been stored, used, or handled in an area that may have subjected them to contamination but the potential for such contamination is low based on process knowledge; however, there is insufficient information to certify that they meet release requirements. In such situations it is not reasonable to require 100% survey of all surfaces. Instead, an approach similar to a confirmatory/verification survey should be used. Item(s) should be surveyed to produce a statistically representative set of measurements that can be used to support process knowledge information or any previous survey data. If these surveys identify contamination, the items should be re-categorized and surveyed consistent with Category 1 items. Examples of property that may warrant Category 2 surveys include:

- Item(s) not exposed to radioactive material in quantities great enough to cause contamination in excess of guidelines.

- Item(s) previously decontaminated for which radiological data are incomplete, or not completely adequate.

- Item(s) for which there is no reason to suspect contamination but there is a significant gap in use history, and they reasonably may have been used in an area that could subject them to contamination.

Scanning should cover as much of the accessible surface of the item(s) as possible. Similarly, static measurements should be done on a statistical basis (some fraction of large items or complete surveys of random samples of some number of small items if the release involves many like items). The need for spot checking areas very difficult to access should be determined on the basis of use history. It is generally recommended that at least some confirmatory/verification measurements be taken in accessible areas. For example, representative samples of fluids in pumps or engines and representative measurements at the openings of input and exhaust ports should be made. However, unless these spot checks indicate contamination, disassembly should not be required for a Category 2 item.

• Special Surface Survey Techniques for Small Items

The determination of average levels of residual radioactive material on surfaces may require relatively long counting times to demonstrate that the authorized limits have been met. For instance, it is not possible to detect 100 dpm/100 cm^2 of Pu-239 with most typical survey probes during a scan-type survey. Therefore, static measurements must be performed. One acceptable approach is to make several static measurements at several representative locations over the surface and average them. Depending on the instrumentation, background, and so forth, counting times from 1 to 3 min may be needed to ensure that 100 dpm/100 cm^2 is detected. However, an alternate approach that covers more surface area is to slowly scan the surface with the survey meter in the integrating mode over the required 1- to 3-min time period. This procedure will provide an acceptable average. Averaging for the integrated scan approach should be limited to areas of about 1 m^2 or less.